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Experimental Identification of the Generalised Four-Element Transfer Matrix for the Pulsating Gas Installation Element Part II-Experiment

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EXPERIMENTAL IDENTIFICATION OF THE GENERALISED FOUR-ELEMENT TRANSFER MATRIX FOR THE PULSATING GAS INSTALLATION ELEMENT PART II-EXPERIMENT

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Abstract

The theoretical basis for the identification procedure for the installation element has been shown in part I. This method is based of the generalized Helmholtz model. The identification procedure has to determine, on the basis of the experiment, four independent transmission matrix elements. In this part the use of worked-up method is shown. The method may be used when the object is mounted in the installation, as well as on the specially designed stand outside the installation. On the stand outside the installation the acoustic speaker have been used as a source of pressure pulsation wave. The basic frequency for the identification experiment should be the same as the basic frequency in the installation, or a "white noise" can be used.

Nomenclature

Scalar values

n – number of harmonics
P – pressure,
ω – frequency.

Complex values

$j=\sqrt{-1}$ – imaginary unit,
P – complex pressure,

Complex matrices

$\mathbf{A}=\{a_{ij}\}$ – four pole matrix,
$\mathbf{Z}=\{z_{ij}\}$ – impedance matrix,
$\mathbf{T}=\{t_{ij}\}$ – transmittance matrix,

1. INTRODUCTION

In the part I presented earlier in this proceedings a complete theory of the experimental identification method for the elements of gas installation has been shown. The method is new, however the way of measurements is similar to earlier works [5].

The main difference is that the basis of the present method is the division of the pressure wave into going forward and backward parts, and introduction of the transmission matrix. This gives the possibility of introducing the correction for average medium velocity to the speed of sound. This part of paper shows the application of the worked out method to the air compressor suction muffler.

2. IDENTIFICATION OF THE INSTALLATION ELEMENT ON A TEST STAND

On the basis of the theory presented in part I research was made in an attempt to find a method of thermodynamic identification of an element, which could be tested experimentally but before placing the identified element in the manifold.

The idea was to assemble a relatively simple test stand on which it would be possible to minimize the effect of other elements of the measurement unit. The elimination of the effect of gas manifold opening and closing on the calculated matrices was carried out by calculation.

Following this idea a test stand was designed (Fig. 1).

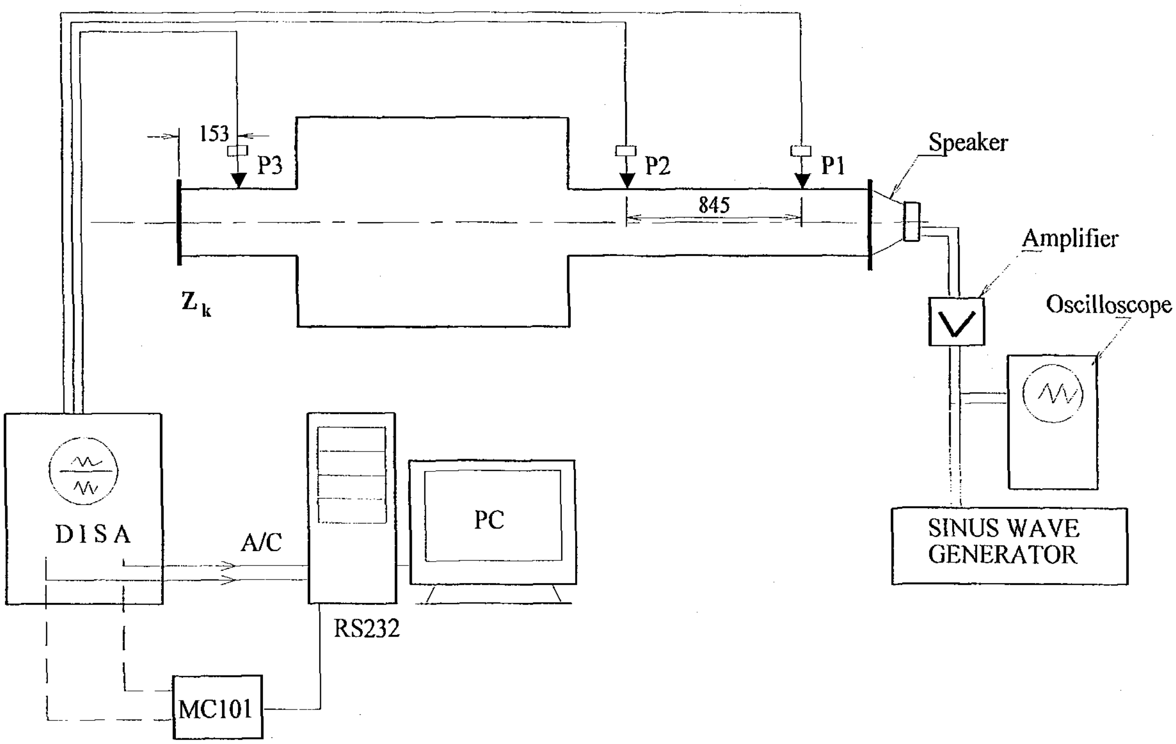

Figure 1 Test stand for the identification of the manifold element.

On the test stand the mounted element is placed between the pressure pulsation source of regulated frequency and amplitude and manifold closing of known impedance. It is necessary to use at least two closing elements of different impedance Z_{k1} and Z_{k2}, and these two values have to be known.

The excitation signal comes from an acoustic loudspeaker.

In the measurement system, as in any manifold, feedback is clearly observed, which combines the reaction of the element with reflections from entrance and closing.

The aim of the proposed identification methods is to eliminate this effect from the measurement results so that complex transmittance matrix **T**, independent of the measurement system was obtained.

In the measurement system, before the tested element, pressure is measured at two points P_1, P_2 separated by a pipeline segment of known diameter and length x_{12}. Following the formulae derived earlier, this allows us to determine the pressure progressive and return waves at point P_2.

$$\left.\begin{bmatrix} P_2^+ \\ P_2^- \end{bmatrix}\right|_{Z_{k1}} = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} \left.\begin{bmatrix} P_3^+ \\ P_3^- \end{bmatrix}\right|_{Z_{k1}} \tag{1a}$$

$$\left.\begin{bmatrix} P_2^+ \\ P_2^- \end{bmatrix}\right|_{Z_{k2}} = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} \left.\begin{bmatrix} P_3^+ \\ P_3^- \end{bmatrix}\right|_{Z_{k2}} \tag{1b}$$

Knowing the closing impedance Z_{k1}, Z_{k2} the progressive and return waves at point 3 can be calculated in the same way. In equations (1a) and (1b) transmittance matrix **T** is the same (because the element did not change). After these equations have been written out, a set of equations 4 x 4 is obtained, which allows us to calculate four unknown elements of matrix **T**.

In this way the identification of the investigated element is unique.

3. APPLICATION OF THE METHOD FOR THE AIR COMPRESSOR MUFFLER

The aim of the experimental verification was to find out whether the identified transmittance matrix for the manifold element gives pulsation calculation results more close to reality than the conventional Helmholtz model. To this end tests were run on a pressure pulsation damper of special design. The damper had a non-symmetrical structure (Fig. 2). The special shape of the damper was chosen in such a way that in this case the classical model produced significant errors.

For this damper there was worked out a classical Helmholtz model containing only elements of pipe, tank type.

In order to determine experimentally matrix T_E outside the manifold, a test stand was assembled (Fig. 1).

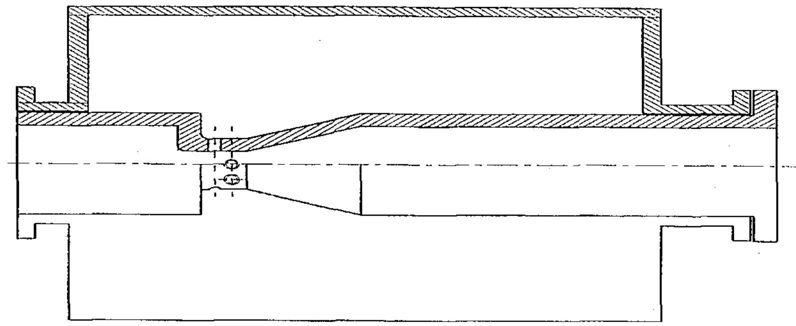

Figure 2. The design of the pulsation damper which has been used for the verification.

For this damper there was worked out a classical Helmholtz model containing only elements of pipe, tank type.

In order to determine experimentally matrix $\mathbf{T}_E$ outside the manifold a test stand was assembled (Fig. 1).

The pressure pulsation excitation source in front of the damper was an acoustic loudspeaker GDN 16/15 (TONSIL). The loudspeaker was fed from a RC oscillator of 20 [Hz] ÷ 200 [kHz], by amplifier A20 MK II (PRIMARE). Digital frequency meter PFL-20 measured the frequency and the course of amplified and non-amplified voltage delivered to the loudspeaker was observed on oscilloscope monitor. The measurement system consisted of three capacitance transducers of pressure Pu2a type produced by DISA. The transducers were connected to MC-101 Transient Recorder unit by a converter and DISA amplifying system. The signal was transmitted to the computer by RS-232 and registered for further processing. The variations of pressure pulsations were observed on DISA oscilloscope. The measurement system was calibrated statically.

The aim of the experiment was to determine function p(τ) for three measuring points (shown in Figs 1) for various excitation frequencies. It is also possible to use the so-called white noise in the range of measured frequencies, which helps to make the calculations faster. In the experiment described here, however, excitation by single harmonic frequencies was used in order to check the validity of the principle of superposition. The measurement was carried out for two impedances closing the system: completely open end, and completely closed end (Fig 1)

After the measurement and determination of p(τ) curves, the following calculations were performed:

- complex functions $P_1(\mathbf{n}\omega)$, $P_2(\boldsymbol{n}\omega)$, $P_3(\boldsymbol{n}\omega)$ (where $\boldsymbol{n}$ - the number of harmonic) were determined by Fourier transform,
- the values P_1, P_2, P_3 determined in the amplitude-frequency complex domain were decomposed for opened and closed system, from which P_1^+, P_1^-, P_2^+, P_2^-, P_3^+, P_3^- were derived.
- with data P_2^+, P_2^- and P_3^+, P_3^- for two different closing Γ_k of the investigated system, on the basis of dependencies (1 a, b) elements $\{t_{ij}\}$ of transmittance matrix were determined.

For experimental verification of the calculated matrices a measurement system based on air compressor S2P216 was used. The compressor operated in Ward-Leonard system with continuous control of rotational speed possible.

On the stand there was mounted the tested acoustic damper in the compressor suction manifold. The measurement system consisted of DISA capacitance transducers, joined to transient recorder MC 101 by a converter and an amplifier, and next to the computer. The measured courses of P_2 and P_3 were the basis for the comparison of the results.

4. VERIFICATION OF THE METHOD WITH THE COMPARISON WITH HELMHOLTZ MODEL

The pressure pulsation measurements let us calculate the pressure transmittance matrix for the damper shown in Fig. 1 for multiplicity of excitation frequencies 21,7 [Hz], which corresponds to rotational compressor speed of 1300 [rpm].

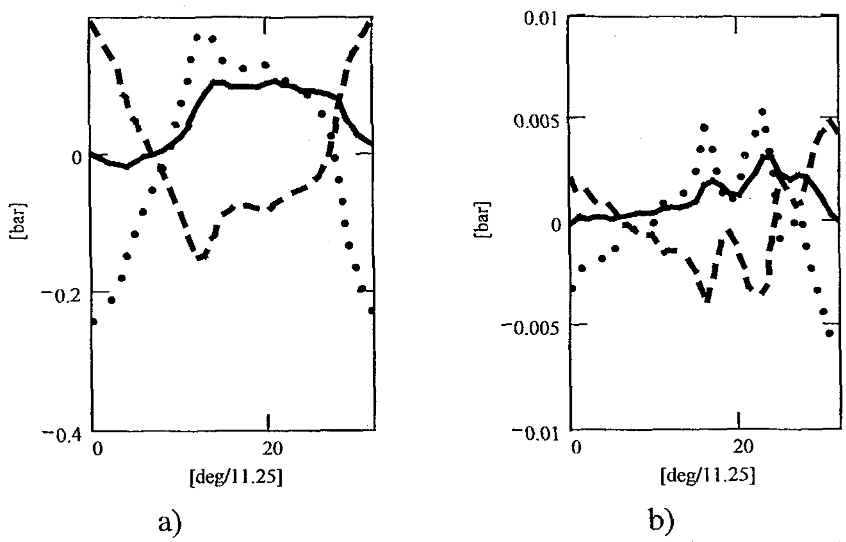

Figure 3. Resolved pressure pulsation at the inlet a) and outlet b) of the pulsation damper. Continuous line denotes p, dotted line denotes p^+, and dashed line denotes p^-.

After mounting the damper on the test stand at the compressor S2P216 inlet manifold, pressure pulsations were measured for the rotational speed corresponding to these frequencies. The measured pressure pulsations were resolved at similar points 2 and 3 into progressing p^+ and returning p^- components. For 1300 [rpm] this resolution was shown in Figs 3.

To verify the method real curves of p_3^+ and p_3^- were used. On their basis, by means of the calculated complex transforms: $\mathbf{T}_E$ - by the experimental method and $\mathbf{T}_T$ - by the classical Helmholtz method, p_2^+, p_2^- and in consequence p_{2T} and p_{2E} were calculated. Then they were compared with the p_2 curves measured on the stand. The comparison of the pressure pulsation curves together with harmonic analysis was presented in Figs 4 and 5. The results were also compared in diagrams with the results obtained in the same way, but with the application of the classical Helmholtz method for determining matrix **T**.

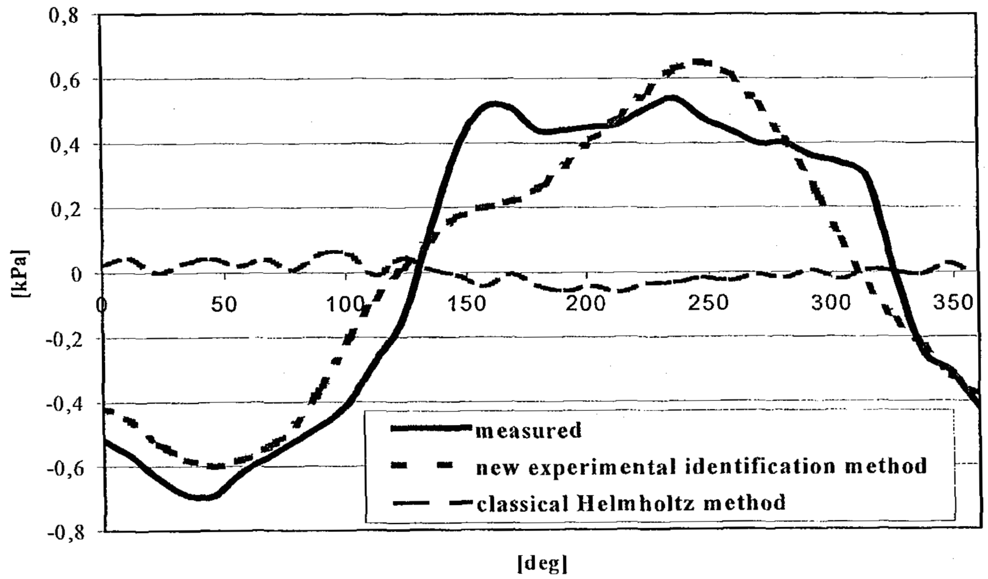

Figure 4. Comparison of the pressure pulsation curves before the damper (P2) obtained by three methods.

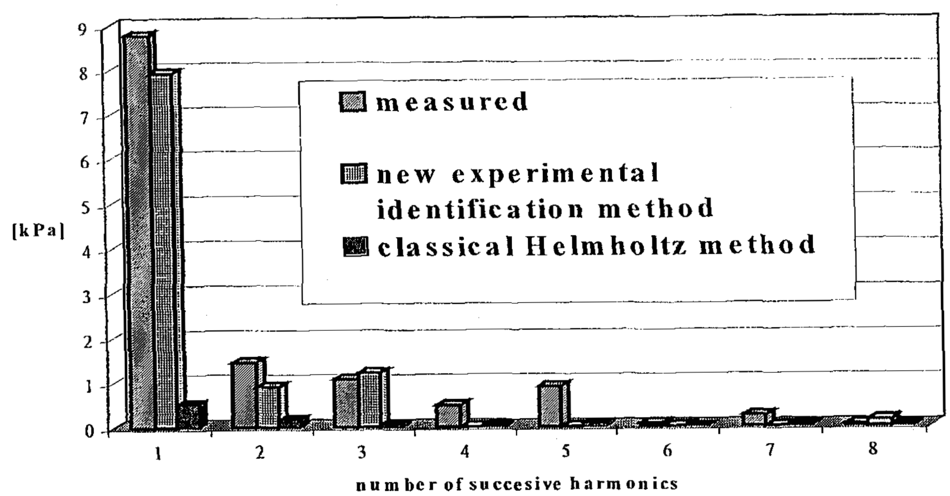

Figure 5. Comparison of the harmonic analysis results for the curves from Fig. 4.

In addition, Table 1 shows the comparison of pressure pulsation peak-to-peak amplitudes for two compressor revolution speeds. For lower revolution speed the results are slightly worst but the identification method is still much better than the classical Helmholtz based model. Problems with identification at low frequencies were caused by poor speaker reactions for low frequencies (below 20 [Hz]), so the method was less accurate. Still however this comparison gives an objective, numerical comparative picture of both methods: classical Helmholtz and identification method worked out.

Table 1. Comparison of the peak-to-peak amplitudes of pressure pulsations.

[rev/min]	Experiment	Helmholtz method		Identification method	
	Δp [kPa]	Δp [kPa]	error [%]	Δp [kPa]	error [%]
700	4,1	1,4	66 %	3,0	26 %
1300	12,5	1,2	90 %	12,3	1,6 %

From the diagrams and the table it follows that definitely better results of identification are obtained using the experimental identification method presented here. The classical Helmholtz method gives damping of the pulsation damper lower by an order of magnitude, because pressure amplitudes ratio at before and after the damper is smaller.

Similar good results were obtained for the real gas refrigerating compressor oil separator with valves, mounted in the discharge manifold [1].

On the basis of these results the author's opinion is that the proposed procedure of thermodynamic identification is promising. Considering the sound theoretical basis of the method, it can be concluded that the obtained results are not accidental and the method can be safely used for thermodynamic identification of gas manifold elements before they are actually mounted.

5.CONCLUSIONS

The most important conclusions of the present paper are:

1. It is possible to identify experimentally four elements of the matrix describing the acoustic reaction of any element of the manifold, only on the basis of measured pressure pulsation curves at selected points of the manifold, and dividing them into going forwards and backwards waves.
2. Such identification gives definitely better results than those obtained by the classical Helmholtz method used so far.

The approach presented in the paper is based on the idea, not used in this field so far, of complex matrix of pressure transmittance T and division of pressure pulsation waves into progressing p^+ and returning p^- waves. This approach made it possible to solve two important problems:

- identification of any element, i.e. calculation of matrix **T** components by means of experimental tests,
- experimental verification of the method only by means of measurements of transient pressure easy to carry out on the network.

On the basis of the investigation and experimental verification results the following conclusions for these methods can be formulated:

- the application of thermodynamic identification methods for complex or non-typical elements of manifold gives only minor errors in comparison with the classical Helmholtz method used so far,
- in some cases, when the inner structure of the element is not known, the application of these methods id the only possibility,
- the discrepancy in investigation results and calculations, when certain matrices **T** are used, results from the following causes:

a) Measurement phase and amplitude error when determining matrix **T**.

b) Non-linearity of the phenomenon. Since the results processing is linearisation in the range of measured parameters, the best results are obtained when the pressure pulsation excitation amplitude during identification tests is of the same order as the one in real manifold;

c) Element identification should be done at the same basic excitation frequency ω and its multiplicity $\underline{n}\omega$ because of considerable irregularity of function $T(\omega)$. Linearisation, done later, of matrix $T(\omega)$ elements between two neighbouring frequencies may not allow obtaining the expected accuracy of calculations.

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